MVSem WS2022/23

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Dynamics of galaxies, star clusters and planetary systems

Abstracts topics J* (**Just**), S* (**Spurzem**)

<u>Milky Way:</u> J1, J2, J4, J5, J6 (disc); -- (bar); -- (halo)

<u>Star Cluster</u>: S2b, S3, S5, S6, S7, F1, F2; <u>Galaxies:</u> J3, J7

<u>Planetary systems</u>: S1, S4, F3, F4, F5, F6, F7, F8

Galactic Nuclei: S2a, S8

J1 <taken>

3D hydrodynamic simulations for the formation of the Local Group satellite planes

Show affiliations

Banik, Indranil ; Thies, Ingo ; Truelove, Roy ; Candlish, Graeme ; Famaey, Benoit ; Pawlowski, Marcel S. ; Ibata, Rodrigo ; Kroupa, Pavel

The existence of mutually correlated thin and rotating planes of satellite galaxies around both the Milky Way (MW) and Andromeda (M31) calls for an explanation. Previous work in Milgromian dynamics (MOND) indicated that a past MW-M31 encounter might have led to the formation of these satellite planes. We perform the first-ever hydrodynamical MOND simulation of the Local Group using PHANTOM OF RAMSES. We show that an MW-M31 encounter at $z \asymp 1$, with a perigalactic distance of about 80 kpc, can yield two disc galaxies at $z = 0$ oriented similarly to the observed galactic discs and separated similarly to the observed M31 distance. Importantly, the tidal debris are distributed in phase space similarly to the observed MW and M31 satellite planes, with the correct preferred orbital pole for both. The MW-M31 orbital geometry is consistent with the presently observed M31 proper motion despite this not being considered as a constraint when exploring the parameter space. The mass of the tidal debris around the MW and M31 at $z = 0$ compare well with the mass observed in their satellite systems. The remnant discs of the two galaxies have realistic radial scale lengths and velocity dispersions, and the simulation naturally produces a much hotter stellar disc in M31 than in the MW. However, reconciling this scenario with the ages of stellar populations in satellite galaxies would require that a higher fraction of stars previously formed in the outskirts of the progenitors ended up within the tidal debris, or that the MW-M31 interaction occurred at $z > 1$.

Publication: Monthly Notices of the Royal Astronomical Society, Volume 513, Issue 1, pp.129-158

Pub Date: June 2022

J2 <taken>

A time-resolved picture of our Milky Way's early formation history

Show affiliations

Xiang, Maosheng iD ; Rix, Hans-Walter iD

The formation of our Milky Way can be split up qualitatively into different phases that resulted in its structurally different stellar populations: the halo and the disk components[1-3]. Revealing a quantitative overall picture of our Galaxy's assembly requires a large sample of stars with very precise ages. Here we report an analysis of such a sample using subgiant stars. We find that the stellar age-metallicity distribution p(τ, [Fe/H]) splits into two almost disjoint parts, separated at age τ ≃ 8 Gyr. The younger part reflects a late phase of dynamically quiescent Galactic disk formation with manifest evidence for stellar radial orbit migration[4-6]; the other part reflects the earlier phase, when the stellar halo[7] and the old α-process-enhanced (thick) disk[8,9] formed. Our results indicate that the formation of the Galaxy's old (thick) disk started approximately 13 Gyr ago, only 0.8 Gyr after the Big Bang, and 2 Gyr earlier than the final assembly of the inner Galactic halo. Most of these stars formed around 11 Gyr ago, when the Gaia-Sausage-Enceladus satellite merged with our Galaxy[10,11]. Over the next 5-6 Gyr, the Galaxy experienced continuous chemical element enrichment, ultimately by a factor of 10, while the star-forming gas managed to stay well mixed.

Publication: Nature, Volume 603, Issue 7902, p.599-603

Pub Date: March 2022

J3 <taken>

Measuring the Milky Way mass distribution in the presence of the LMC

Show affiliations

Correa Magnus, Lilia ; Vasiliev, Eugene iD

The ongoing interaction between the Milky Way (MW) and its largest satellite - the Large Magellanic Cloud (LMC) - creates a significant perturbation in the distribution and kinematics of distant halo stars, globular clusters and satellite galaxies, and leads to biases in MW mass estimates from these tracer populations. We present a method for compensating these perturbations for any choice of MW potential by computing the past trajectory of LMC and MW and then integrating the orbits of tracer objects back in time until the influence of the LMC is negligible, at which point the equilibrium approximation can be used with any standard dynamical modelling approach. We add this orbit-rewinding step to the mass estimation approach based on simultaneous fitting of the potential and the distribution function of tracers, and apply it to two data sets with the latest Gaia EDR3 measurements of 6D phase-space coordinates: globular clusters and satellite galaxies. We find that models with LMC mass in the range $(1-2) \times 10^{11}\, M_\odot$ better fit the observed distribution of tracers, and measure MW mass within 100 kpc to be $(0.75 \pm 0.1) \times 10^{12}\, M_\odot$, while neglecting the LMC perturbation increases it by ~15 per cent.

Publication: Monthly Notices of the Royal Astronomical Society, Volume 511, Issue 2, pp.2610-2630

Pub Date: April 2022

J4 **<taken>**

The velocity distribution of white dwarfs in Gaia EDR3

Show affiliations

Mikkola, Daniel ; McMillan, Paul J. iD ; Hobbs, David ; Wimarsson, John

Using a penalized maximum likelihood, we estimate, for the first time, the velocity distribution of white dwarfs in the solar neighbourhood. Our sample consists of 129 675 white dwarfs within 500 pc in Gaia Early Data Release 3. The white dwarf velocity distributions reveal a similar structure to the rest of the solar neighbourhood stars, reflecting that white dwarfs are subject to the same dynamical processes. In the velocity distribution for three magnitude-binned subsamples, we, however, find a novel structure at (U, V) = (7, -19) km s^{-1} in fainter samples, potentially related to the Coma Berenices stream. We also see a double-peaked feature in U - W at U $\asymp$ -30 km s^{-1} and in V - W at V $\asymp$ -20 km s^{-1} for fainter samples. We determine the velocity distribution and velocity moments as a function of absolute magnitude for two samples based on the bifurcation identified in Gaia Data Release 2 in the colour-magnitude diagram. The brighter, redder sequence has a larger velocity dispersion than the fainter, bluer sequence across all magnitudes. It is hard to reconcile this kinematic difference with a bifurcation caused purely by atmospheric composition, while it fits neatly with a significant age difference between the two sequences. Our results provide novel insights into the kinematic properties of white dwarfs and demonstrate the power of analytical techniques that work for the large fraction of stars that do not have measured radial velocities in the current era of large-scale astrometric surveys.

Publication:	Monthly Notices of the Royal Astronomical Society, Volume 512, Issue 4, pp.6201-6216
Pub Date:	June 2022

The disturbed outer Milky Way disc

Show affiliations

McMillan, Paul J. ; Petersson, Jonathan ; Tepper-Garcia, Thor ; Bland-Hawthorn, Joss ; Antoja, Teresa ; Chemin, Laurent ; Figueras, Francesca ; Khanna, Shourya ; Kordopatis, Georges ; Ramos, Pau ; Romero-Gómez, Merce ; Seabroke, George

The outer parts of the Milky Way's disc are significantly out of equilibrium. Using only distances and proper motions of stars from Gaia's Early Data Release 3, in the range $|b| < 10°$, $130° < \ell < 230°$, we show that for stars in the disc between around 10 and $14\,\mathrm{kpc}$ from the Galactic centre, vertical velocity is strongly dependent on the angular momentum, azimuth, and position above or below the Galactic plane. We further show how this behaviour translates into a bimodality in the velocity distribution of stars in the outer Milky Way disc. We use an N-body model of an impulse-like interaction of the Milky Way disc with a perturber similar to the Sagittarius dwarf to demonstrate that this mechanism can generate a similar disturbance. It has already been shown that this interaction can produce a phase spiral similar to that seen in the Solar neighbourhood. We argue that the details of this substructure in the outer galaxy will be highly sensitive to the timing of the perturbation or the gravitational potential of the Galaxy, and therefore may be key to disentangling the history and structure of the Milky Way.

J6

Our Galaxy's youngest disc

Show affiliations

Li, Chengdong iD ; Binney, James iD

We investigate the structure of our Galaxy's young stellar disc by fitting the distribution functions (DFs) of a new family to 5D Gaia data for a sample of $47\,000$ OB stars. Tests of the fitting procedure show that the young disc's DF would be strongly constrained by Gaia data if the distribution of Galactic dust were accurately known. The DF that best fits the real data accurately predicts the kinematics of stars at their observed locations, but it predicts the spatial distribution of stars poorly, almost certainly on account of errors in the best-available dust map. We argue that dust models could be greatly improved by modifying the dust model until the spatial distribution of stars predicted by a DF agreed with the data. The surface density of OB stars is predicted to peak at $R \simeq 5.5\,\mathrm{kpc}$, slightly outside the reported peak in the surface density of molecular gas; we suggest that the latter radius may have been underestimated through the use of poor kinematic distances. The velocity distributions predicted by the best-fitting DF for stars with measured line-of-sight velocities $v_\parallel$ reveal that the outer disc is disturbed at the level of $10\,\mathrm{km\,s^{-1}}$ in agreement with earlier studies, and that the measured values of $v_\parallel$ have significant contributions from the orbital velocities of binaries. Hence the outer disc is colder than it is sometimes reported to be.

J7 <reserved>

The Dawn of Disk Formation in a Milky Way-sized Galaxy Halo: Thin Stellar Disks at z > 4

We present results from GIGAERIS, a cosmological, N-body hydrodynamical "zoom-in" simulation of the formation of a Milky Way-sized galaxy halo with unprecedented resolution, encompassing of order a billion particles within the refined region. The simulation employs a modern implementation of smoothed-particle hydrodynamics, including metal-line cooling and metal and thermal diffusion. We focus on the early assembly of the galaxy, down to redshift z = 4.4. The simulated galaxy has properties consistent with extrapolations of the main sequence of star-forming galaxies to higher redshifts and levels off to a star formation rate of ~60 $M_\odot$ yr^{-1} at z = 4.4. A compact, thin rotating stellar disk with properties analogous to those of low-redshift systems arises already at z ~ 8. The galaxy rapidly develops a multi-component structure, and the disk, at least at these early stages, does not grow "upside-down" as often reported in the literature. Rather, at any given time, newly born stars contribute to sustain a thin disk. The kinematics reflect the early, ubiquitous presence of a thin disk, as a stellar disk component with v_ϕ/σ_R larger than unity is already present at z ~ 9-10. Our results suggest that high-resolution spectro-photometric observations of very high-redshift galaxies should find thin rotating disks, consistent with the recent discovery of cold rotating gas disks by ALMA. Finally, we present synthetic images for the James Webb Space Telescope NIRCam camera, showing how the early disk would be easily detectable already at those early times.

S1 **<taken>**

On the Correlation between Hot Jupiters and Stellar Clustering: High-eccentricity Migration Induced by Stellar Flybys

Show affiliations

Rodet, Laetitia ; Su, Yubo ; Lai, Dong

A recent observational study suggests that the occurrence of hot Jupiters (HJs) around solar-type stars is correlated with stellar clustering. We study a new scenario for HJ formation, called "Flyby Induced High-e Migration," that may help explain this correlation. In this scenario, stellar flybys excite the eccentricity and inclination of an outer companion (giant planet, brown dwarf, or low-mass star) at large distance (10-300 au), which then triggers high-e migration of an inner cold Jupiter (at a few astronomical units) through the combined effects of von Zeipel-Lidov-Kozai (ZLK) eccentricity oscillation and tidal dissipation. Using semianalytical calculations of the effective ZLK inclination window, together with numerical simulations of stellar flybys, we obtain the analytic estimate for the HJ occurrence rate in this formation scenario. We find that this "flyby induced high-e migration" could account for a significant fraction of the observed HJ population, although the result depends on several uncertain parameters, including the density and lifetime of birth stellar clusters, and the occurrence rate of the "cold Jupiter + outer companion" systems.

Publication: The Astrophysical Journal, Volume 913, Issue 2, id.104, 8 pp.

Pub Date: June 2021

S2a <taken>

Improved gravitational radiation time-scales II: Spin-orbit contributions and environmental perturbations

Peters' formula is an analytical estimate of the time-scale of gravitational wave (GW)-induced coalescence of binary systems. It is used in countless applications, where the convenience of a simple formula outweighs the need for precision. However, many promising sources of the Laser Interferometer Space Antenna (LISA), such as supermassive black hole binaries and extreme mass-ratio inspirals (EMRIs), are expected to enter the LISA band with highly eccentric ($e \gtrsim 0.9$) and highly relativistic orbits. These are exactly the two limits in which Peters' estimate performs the worst. In this work, we expand upon previous results and give simple analytical fits to quantify how the inspiral time-scale is affected by the relative 1.5 post-Newtonian (PN) hereditary fluxes and spin-orbit couplings. We discuss several cases that demand a more accurate GW time-scale. We show how this can have a major influence on quantities that are relevant for LISA event-rate estimates, such as the EMRI critical semimajor axis. We further discuss two types of environmental perturbations that can play a role in the inspiral phase: the gravitational interaction with a third massive body and the energy loss due to dynamical friction and torques from a surrounding gas medium ubiquitous in galactic nuclei. With the aid of PN corrections to the time-scale in vacuum, we find simple analytical expressions for the regions of phase space in which environmental perturbations are of comparable strength to the effects of any particular PN order, being able to qualitatively reproduce the results of much more sophisticated analyses.

S2b **<taken>**

Compact object mergers in hierarchical triples from low-mass young star clusters

A binary star orbited by an outer companion constitutes a hierarchical triple system. The outer body may excite the eccentricity of the inner binary through the von Zeipel-Lidov-Kozai (ZLK) mechanism, triggering the gravitational wave (GW) coalescence of the inner binary when its members are compact objects. Here, we study a sample of hierarchical triples with an inner black hole (BH) - BH binary, BH - neutron star (NS) binary, and BH - white dwarf (WD) binary, formed via dynamical interactions in low-mass young star clusters. Our sample of triples was obtained self-consistently from direct N-body simulations of star clusters, which included up-to-date stellar evolution. We find that the inner binaries in our triples cannot merge via GW radiation alone, and the ZLK mechanism is essential to trigger their coalescence. Contrary to binaries assembled dynamically in young star clusters, binary BHs merging in triples have preferentially low-mass ratios ($q \simeq 0.3$) and higher primary masses ($m_{\rm p} \gtrsim 40\,{\rm M_\odot}$). We derive a local merger rate density of 0.60, 0.11, and $0.5\,{\rm yr^{-1}\,Gpc^{-3}}$ for BH-BH, BH-NS, and BH-WD binaries, respectively. Additionally, we find that merging binaries have high eccentricities across the GW spectrum, including the LIGO-Virgo-KAGRA (LVK), LISA, and DECIGO frequencies. About 7 per cent of BH-BH and 60 per cent of BH-NS binaries will have detectable eccentricities in the LVK band. Our results indicate that the eccentricity and the mass spectrum of merging binaries are the strongest features for the identification of GW mergers from triples.

S3

The dynamics of the globular cluster NGC 3201 out to the Jacobi radius

Show affiliations

Wan, Zhen ; Oliver, William H. ; Baumgardt, Holger ; Lewis, Geraint F. ; Gieles, Mark ; Hénault-Brunet, Vincent ; de Boer, Thomas ; Balbinot, Eduardo ; Da Costa, Gary ; Mackey, Dougal

As part of a chemodynamical survey of five nearby globular clusters with 2dF/AAOmega on the Anglo-Australian Telescope (AAT), we have obtained kinematic information for the globular cluster NGC 3201. Our new observations confirm the presence of a significant velocity gradient across the cluster which can almost entirely be explained by the high proper motion of the cluster ($\sim 9\,\mathrm{mas\,yr^{-1}}$). After subtracting the contribution of this perspective rotation, we found a remaining rotation signal with an amplitude of $\sim 1\,\mathrm{km\,s^{-1}}$ around a different axis to what we expect from the tidal tails and the potential escapers, suggesting that this rotation is internal and can be a remnant of its formation process. At the outer part, we found a rotational signal that is likely a result from potential escapers. The proper motion dispersion at large radii reported by Bianchini et al. ($3.5 \pm 0.9\,\mathrm{km\,s^{-1}}$) has previously been attributed to dark matter. Here, we show that the LOS dispersion between 0.5 and 1 Jacobi radius is lower ($2.01 \pm 0.18\,\mathrm{km\,s^{-1}}$), yet above the predictions from an N-body model of NGC 3201 that we ran for this study ($1.48 \pm 0.14\,\mathrm{km\,s^{-1}}$). Based on the simulation, we find that potential escapers cannot fully explain the observed velocity dispersion. We also estimate the effect on the velocity dispersion of different amounts of stellar-mass black holes and unbound stars from the tidal tails with varying escape rates and find that these effects cannot explain the difference between the LOS dispersion and the N-body model. Given the recent discovery of tidal tail stars at large distances from the cluster, a dark matter halo is an unlikely explanation. We show that the effect of binary stars, which is not included in the N-body model, is important and can explain part of the difference in dispersion. We speculate that the remaining difference must be the result of effects not included in the N-body model, such as initial cluster rotation, velocity anisotropy, and Galactic substructure.

Publication: Monthly Notices of the Royal Astronomical Society, Volume 502, Issue 3, pp.4513-4525

Pub Date: April 2021

S4 **<taken>**

Migrating Planets into Ultra-short-period Orbits during Episodic Accretion Events

Show affiliations

Becker, Juliette C. ; Batygin, Konstantin ; Adams, Fred C.

Ultra-short-period (USP) planets reside inside the expected truncation radius for typical T Tauri disks. As a result, their current orbital locations require an explanation beyond standard disk migration or in situ formation. Modern theories of planet-disk interactions indicate that once a planet migrates close to the disk's inner truncation radius, Type I torques vanish or switch direction, depending on the stellar and disk conditions, so that the planet is expected to stop its orbital decay and become trapped. In this work, we show that that magnetically driven sub-Keplerian gas flow in the inner disk can naturally counteract these effects and produce systems with USP planets at their observed orbital radii. The sub-Keplerian gas flow provides a headwind to small planets, and the resulting torque can overcome the effects of outward Type I migration near the corotation radius. For suitable disk and planet parameters, the torques due to the sub-Keplerian gas flow lead to inward migration on a rapid timescale. Over the time span of an FU Ori outburst, which moves the disk truncation radius inward, the rapid headwind migration can place planets in USP orbits. The combination of headwind migration and FU Ori outbursts thus provides a plausible mechanism to move small planets from a = 0.05-0.1 au down to a = 0.01-0.02 au. This effect is amplified for low-mass planets, consistent with existing observations.

Publication: The Astrophysical Journal, Volume 919, Issue 2, id.76, 9 pp.

Pub Date: October 2021

S5 **<taken>**

Close Stellar Flybys Common in Low-mass Clusters

Show affiliations

Pfalzner, Susanne ; Govind, Amith

Numerous protoplanetary disks show distinct spiral arms features. While possibly caused by a range of processes, detailed pattern analysis points at close stellar flybys as cause for some of them. Surprisingly, these disks reside in young low-mass clusters, where close stellar flybys are expected to be rare. This fact motivated us to take a fresh look at the frequency of close flybys in low-mass clusters. In the solar neighborhood, low-mass clusters have smaller half-mass radii than their more massive counterparts. We show that this observational fact results in the mean and central stellar density of low-mass clusters being approximately the same as in high-mass clusters, which is rarely reflected in theoretical studies. We perform N-body simulations of the stellar dynamics in young clusters obeying the observed mass-radius relation. Taking the mean disk truncation radius as a proxy for the degree of influence of the environment, we find that the influence of the environment on disks is more or less the same in low- and high-mass clusters. Even the fraction of small disks (<10 au) is nearly identical. Our main conclusion is that the frequency of close flybys seems to have been severely underestimated for low-mass clusters. A testable prediction of this hypothesis is that low-mass clusters should contain 10%-15% of disks smaller than 30 au truncated by flybys. These truncated disks should be distinguishable from primordially small disks by their steep outer edge.

Publication: The Astrophysical Journal, Volume 921, Issue 1, id.90, 13 pp.

Pub Date: November 2021

S6

Mass segregation and dynamics of primordial binaries in star clusters with a radially anisotropic velocity distribution

Show affiliations

Pavlík, Václav ; Vesperini, Enrico

This paper is the third in a series investigating, by means of N-body simulations, the implications of an initial radially anisotropic velocity distribution on the dynamics of star clusters. Such a velocity distribution may be imprinted during a cluster's early evolutionary stages and several observational studies have found examples of old globular clusters in which radial anisotropy is still present in the current velocity distribution. Here we focus on its influence on mass segregation and the dynamics of primordial binary stars (disruptions, ejections, and component exchanges). The larger fraction of stars on radial/highly eccentric orbits in the outer regions of anisotropic clusters lead to an enhancement in the dynamical interactions between inner and outer stars that affects both the process of mass segregation and the evolution of primordial binaries. The results of our simulations show that the time-scale of mass segregation of the initially anisotropic cluster is longer in the core and shorter in the outer regions, when compared to the initially isotropic system. The evolution of primordial binaries is also significantly affected by the initial velocity distribution and we find that the rate of disruptions, ejections, and exchange events affecting the primordial binaries in the anisotropic clusters is higher than in the isotropic ones.

S7

The role of rotation on the formation of second generation stars in globular clusters

Show affiliations

Lacchin, E. ; Calura, F. ; Vesperini, E. ; Mastrobuono-Battisti, A.

By means of 3D hydrodynamic simulations, we explore the effects of rotation in the formation of second-generation (SG) stars in globular clusters (GC). Our simulations follow the SG formation in a first-generation (FG) internally rotating GC; SG stars form out of FG asymptotic giant branch (AGB) ejecta and external pristine gas accreted by the system. We have explored two different initial rotational velocity profiles for the FG cluster and two different inclinations of the rotational axis with respect to the direction of motion of the external infalling gas, whose density has also been varied. For a low (10^{-24} g cm^{-3}) external gas density, a disc of SG helium-enhanced stars is formed. The SG is characterized by distinct chemo-dynamical phase space patterns: it shows a more rapid rotation than the FG with the helium-enhanced SG subsystem rotating more rapidly than the moderate helium-enhanced one. In models with high external gas density (10^{-23} g cm^{-3}), the inner SG disc is disrupted by the early arrival of external gas and only a small fraction of highly enhanced helium stars preserves the rotation acquired at birth. Variations in the inclination angle between the rotation axis and the direction of the infalling gas and the velocity profile can slightly alter the extent of the stellar disc and the rotational amplitude. The results of our simulations illustrate the complex link between dynamical and chemical properties of multiple populations and provide new elements for the interpretation of observational studies and future investigations of the dynamics of multiple-population GCs.

Publication: Monthly Notices of the Royal Astronomical Society, Volume 517, Issue 1, pp.1171-1188

Pub Date: November 2022

S8 **<taken>**

Global instability by runaway collisions in nuclear stellar clusters: Numerical tests of a route for massive black hole formation

Show affiliations

Vergara, M. C. ; Escala, A. ; Schleicher, D. R. G. ; Reinoso, B.

The centers of galaxies host nuclear stellar clusters, supermassive black holes, or both, but the origin of this dichotomy is still a mystery. Nuclear stellar clusters are the densest stellar system of the Universe, so they are ideal places for runaway collisions to occur. In these dense clusters it is possible that global instability occurs, triggered by collisions and mergers forming a massive black hole. Here we test a new mechanism to form massive black holes through runaway stellar collisions in nuclear stellar clusters, performing N-body simulations using the code nbody6++gpu. Our idealized models show that there is a critical mass where collisions become very efficient making it possible to form massive black holes in nuclear stellar clusters. The most massive objects reach masses of the order of $10^4 - 10^5\ \mathrm{M}_\odot$. We find that our highest black hole formation efficiency is up to 50% of the stellar mass at the end of the simulation. In real astrophysical systems, the critical mass scale for this transition is expected to occur in stellar clusters of $10^7 - 10^9\ \mathrm{M}_\odot$, implying the formation of quite massive central objects.

Publication: eprint arXiv:2209.15066

Pub Date: September 2022

F1 **<taken>**

The 10 parsec sample in the Gaia era

Show affiliations

Reylé, C. ; Jardine, K. ; Fouqué, P. ; Caballero, J. A. ; Smart, R. L. ; Sozzetti, A.

Context. The nearest stars provide a fundamental constraint for our understanding of stellar physics and the Galaxy. The nearby sample serves as an anchor where all objects can be seen and understood with precise data. This work is triggered by the most recent data release of the astrometric space mission Gaia and uses its unprecedented high precision parallax measurements to review the census of objects within 10 pc.
Aims: The first aim of this work was to compile all stars and brown dwarfs within 10 pc observable by Gaia and compare it with the Gaia Catalogue of Nearby Stars as a quality assurance test. We complement the list to get a full 10 pc census, including bright stars, brown dwarfs, and exoplanets.
Methods: We started our compilation from a query on all objects with a parallax larger than 100 mas using the Set of Identifications, Measurements, and Bibliography for Astronomical Data database (SIMBAD). We completed the census by adding companions, brown dwarfs with recent parallax measurements not in SIMBAD yet, and vetted exoplanets. The compilation combines astrometry and photometry from the recent Gaia Early Data Release 3 with literature magnitudes, spectral types, and line-of-sight velocities.
Results: We give a description of the astrophysical content of the 10 pc sample. We find a multiplicity frequency of around 27%. Among the stars and brown dwarfs, we estimate that around 61% are M stars and more than half of the M stars are within the range from M3.0 V to M5.0 V. We give an overview of the brown dwarfs and exoplanets that should be detected in the next Gaia data releases along with future developments.
Conclusions: We provide a catalogue of 540 stars, brown dwarfs, and exoplanets in 339 systems, within 10 pc from the Sun. This list is as volume-complete as possible from current knowledge and it provides benchmark stars that can be used, for instance, to define calibration samples and to test the quality of the forthcoming Gaia releases. It also has a strong outreach potential.

The animation and a zoomable version of Fig. B.1 are available at https://www.aanda.org

Table A.1 is only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (ftp://130.79.128.5) or via http://cdsarc.u-strasbg.fr/viz-bin/cat/J/A+A/650/A201, at https://gruze.org/10pc/, and at https://gucds.inaf.it/

Publication: Astronomy & Astrophysics, Volume 650, id.A201, 14 pp.

Pub Date: June 2021

F2 **<taken>**

Membership of stars in open clusters using random forest with gaia data

Abstract

Membership of stars in open clusters is one of the most crucial parameters in studies of star clusters. Gaia opened a new window in the estimation of membership because of its unprecedented 6-D data. In the present study, we used published membership data of nine open star clusters as a training set to find new members from Gaia DR2 data using a supervised random forest model with a precision of around 90%. The number of new members found is often double the published number. Membership probability of a larger sample of stars in clusters is a major benefit in determination of cluster parameters like distance, extinction and mass functions. We also found members in the outer regions of the cluster and found sub-structures in the clusters studied. The color magnitude diagrams are more populated and enriched by the addition of new members making their study more promising.

F3

THE ASTROPHYSICAL JOURNAL LETTERS, 937:L22 (8pp), 2022 October 1 https://doi.org/10.3847/2041-8213/ac90b9

CrossMark

A Low-inclination Neutral Trans-Neptunian Object in an Extreme Orbit

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Abstract

We present photometric observations and numerical simulations of 2016 SD_{106}, a low-inclination ($i = 4\overset{\circ}{.}8$) extreme trans-Neptunian Object with a large semimajor axis ($a = 350$ au) and perihelion ($q = 42.6$ au). This object possesses a peculiar neutral color of $g - r = 0.45 \pm 0.05$ and $g - i = 0.72 \pm 0.06$, in comparison with other distant trans-Neptunian objects, all of which have moderate-red to ultra-red colors. A numerical integration based on orbital fitting on astrometric data covering eight years of arc confirms that 2016 SD_{106} is a metastable object without significant scattering evolution. Each of the clones survived at the end of the 1 Gyr simulation. However, very few neutral objects with inclinations $<5°$ have been found in the outer solar system, even in the main Kuiper Belt. Furthermore, most mechanisms that lift perihelion distances are expected to produce a very low number of extreme objects with inclinations $<5°$. We thus explored the possibility that a hypothetical distant planet could increase the production of such objects. Our simulations show that no 2016 SD_{106}–like orbits can be produced from three Kuiper Belt populations tested (i.e., plutinos, twotinos, and the Haumea Family) without the presence of a hypothetical planet, while a few similar orbits can be obtained with it; however, the presence of the additional planet produces a wide range of large semimajor-axis/large perihelion objects, in apparent contradiction with the observed scarcity of objects in those regions of phase space. Future studies may determine if there is a connection between the existence of a perihelion gap and a particular orbital configuration of a hypothetical distant planet.

F4

The Astrophysical Journal Letters, 938:L3 (12pp), 2022 October 10

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CrossMark

Reduced Late Bombardment on Rocky Exoplanets around M Dwarfs

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Abstract

Ocean-vaporizing impacts of chemically reduced planetesimals onto the early Earth have been suggested to catalyze atmospheric production of reduced nitrogen compounds and trigger prebiotic synthesis despite an oxidized lithosphere. While geochemical evidence supports a dry, highly reduced late veneer on Earth, the composition of late-impacting debris around lower-mass stars is subject to variable volatile loss as a result of their hosts' extended pre-main-sequence phase. We perform simulations of late-stage planet formation across the M-dwarf mass spectrum to derive upper limits on reducing bombardment epochs in Hadean-analog environments. We contrast the solar system scenario with varying initial volatile distributions due to extended primordial runaway greenhouse phases on protoplanets and the desiccation of smaller planetesimals by internal radiogenic heating. We find a decreasing rate of late-accreting reducing impacts with decreasing stellar mass. Young planets around stars $\leqslant 0.4\ M_{\odot}$ experience no impacts of sufficient mass to generate prebiotically relevant concentrations of reduced atmospheric compounds once their stars have reached the main sequence. For M-dwarf planets to not exceed Earth-like concentrations of volatiles, both planetesimals, and larger protoplanets must undergo extensive devolatilization processes and can typically emerge from long-lived magma ocean phases with sufficient atmophile content to outgas secondary atmospheres. Our results suggest that transiently reducing surface conditions on young rocky exoplanets are favored around FGK stellar types relative to M dwarfs.

F5 <taken>

Production of hot Jupiter candidates from high-eccentricity mechanisms for different initial planetary mass configurations

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Hot Jupiters (HJs) are giant planets with orbital periods of the order of a few days with semimajor axis within $\sim$0.1 au. Several theories have been invoked in order to explain the origin of this type of planets, one of them being the high-eccentricity migration. This migration can occur through different high-eccentricity mechanisms. Our investigation focused on six different kinds of high-eccentricity mechanisms, namely, direct dispersion, coplanar, Kozai-Lidov, secular chaos, E1 and E2 mechanisms. We investigated the efficiency of these mechanisms for the production of HJ candidates in multi-planet systems initially tightly-packed in the semimajor axis, considering a large set of numerical simulations of the exact equations of motion in the context of the N-body problem. In particular, we analyzed the sensitivity of our results to the initial number of planets, the initial semimajor axis of the innermost planetary orbit, the initial configuration of planetary masses, and to the inclusion of general relativity effects. We found that the E1 mechanism is the most efficient in producing HJ candidates both in simulations with and without the contribution of general relativity, followed by the Kozai-Lidov and E2 mechanisms. Our results also revealed that, except for the initial equal planetary mass configuration, the E1 mechanism was notably efficient in the other initial planetary mass configurations considered in this work. Finally, we investigated the production of HJ candidates with prograde, retrograde, and alternating orbits. According to our statistical analysis, the Kozai-Lidov mechanism has the highest probability of significantly exciting the orbital inclinations of the HJ candidates.

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F6

The Possibility of Mirror Planet as Planet Nine in the Solar System

by Pei Wang [1,2], Yuchen Tang [1,2], Lei Zu [1,2,*], Yuanyuan Chen [3,4,5] and Lei Feng [1,6,*]

Abstract

A series of dynamical anomalies in the orbits of distant trans-Neptunian objects points to a new celestial body (usually named Planet Nine) in the solar system. In this draft, we point out that a mirror planet captured from the outer solar system or formed in the solar system is also a possible candidate. The introduction of the mirror matter model is due to an unbroken parity symmetry and is a potential explanation for dark matter. This mirror planet has null or fainter electromagnetic counterparts with a smaller optical radius and might be explored through gravitational effects. **View Full-Text**

F7

The orbital evolution of Atira asteroids

Hsuan-Ting Lai, Wing-Huen Ip

Asteroids having perihelion distance $q <$ 1.3 AU are classified as near-Earth objects (NEOs), which are divided into different sub-groups: Vatira-class, Atira-class, Aten-class, Apollo-class, and Amor-class. 2020 AV_2, the first Vatira (Orbiting totally inside Venus' orbit) was discovered by the Twilight project of the Zwicky Transient Facility (ZTF) on January 4, 2020. Upon the discovery of 2020 AV_2, a couple of orbital studies of the short-term orbital evolution of 2020 AV_2 have been performed and published (e.g. de la Fuente Marcos & de la Fuente Marcos 2020; Greenstreet 2020). In this present work, we performed an assessment of the long-term orbital evolution of known near-Earth objects and known Atiras under the Yarkovsky effect by using the \textit{Mercury6} N-body code. We considered not only planetary gravitational perturbation but also the non-gravitational Yarkovsky effect. Our calculation shows that the NEOs have generally two dynamical populations, one short-lived and the other long-lived. From our calculation, the transfer probabilities of Atira-class asteroids to Vatira-class asteroids for the first transition are $\sim$13.1 $\pm$ 0.400, $\sim$13.05 $\pm$ 0.005, and $\sim$ 13.25 $\pm$ 0.450 $\%$ for different values of the Yarkovsky force (i.e. obliquity of 0, 90, and 180 deg.), respectively. It suggests that the radiation force may play some role in the long-term evolution of this asteroid population. Finally, our statistical study implicates that there should be 8.14 $\pm$ 0.133 Atira-class asteroids and 1.05 $\pm$ 0.075 Vatira-asteroids of the S-type taxonomy.

F8

Stability analysis of planetary systems via second-order Rényi entropy

Tamás Kovács, Máté Pszota, Emese Kővári, Emese Forgács-Dajka, Zsolt Sándor

The long-term dynamical evolution is a crucial point in recent planetary research. Although the amount of observational data is continuously growing and the precision allows us to obtain accurate planetary orbits, the canonical stability analysis still requires N-body simulations and phase space trajectory investigations. We propose a method for stability analysis of planetary motion based on the generalized Rényi entropy obtained from a scalar measurement. The radial velocity data of the central body in the gravitational three-body problem is used as the basis of a phase space reconstruction procedure. Then, Poincaré's recurrence theorem contributes to finding a natural partitioning in the reconstructed phase space to obtain the Rényi entropy. It turns out that the entropy-based stability analysis is in good agreement with other chaos detection methods, and it requires only a few tens of thousands of orbital period integration time.

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